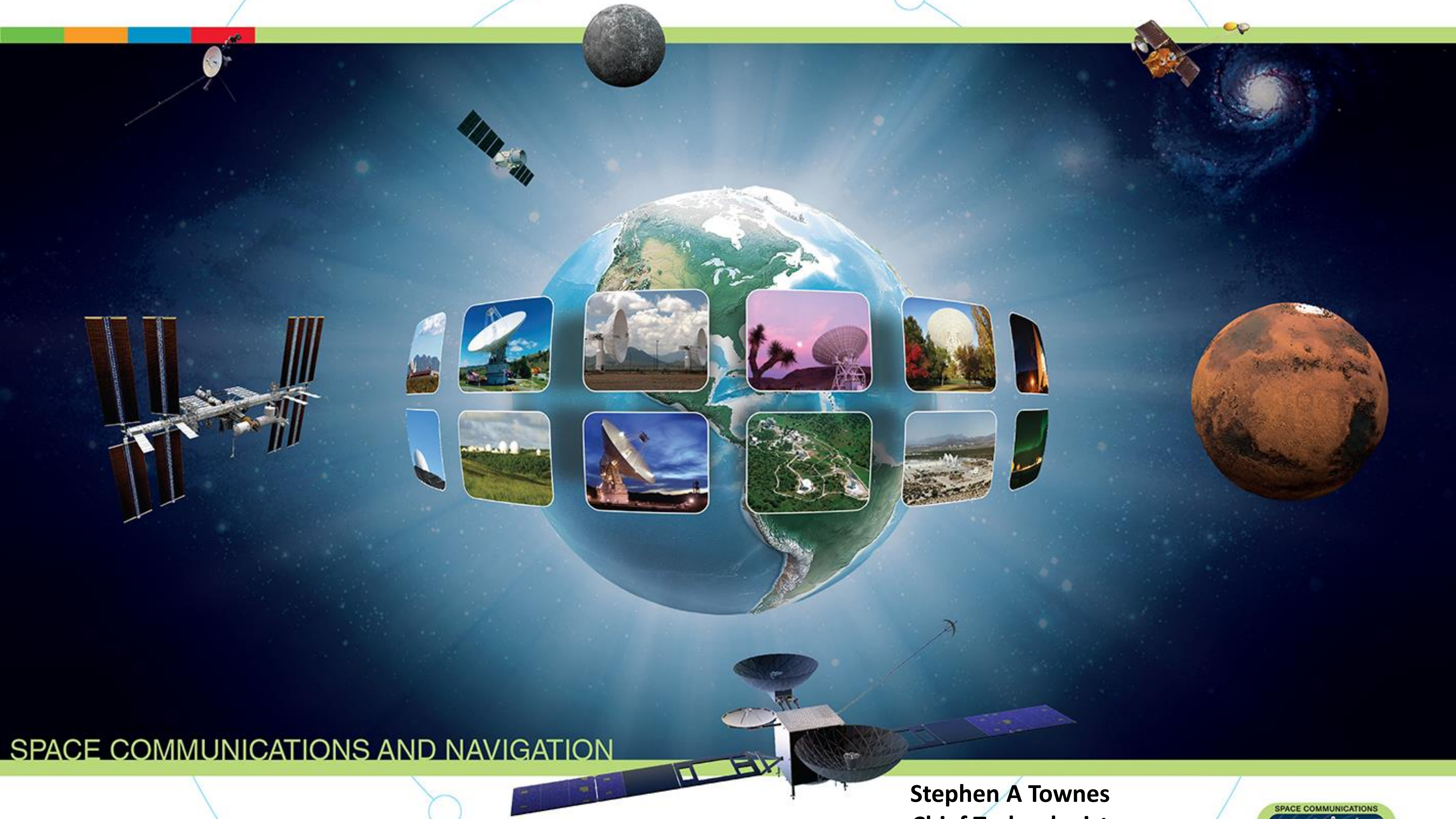
ESA-NASA/JPL Technical Interchange

National Aeronautics and Space Administration



Stephen A Townes
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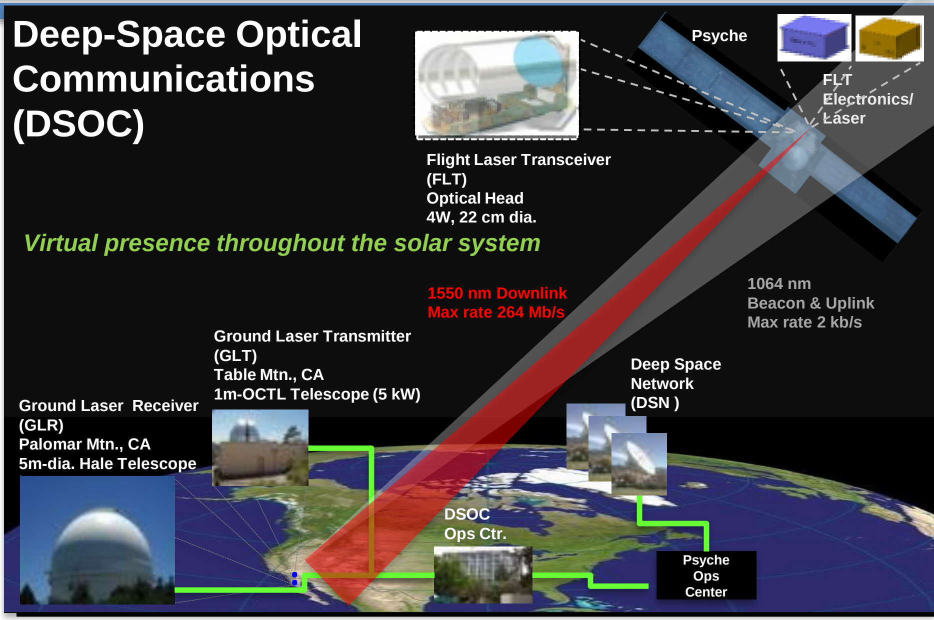
Deep Space Optical Communications (DSOC)

Bill Klipstein, Project Manager
Abi Biswas, Project Technologist

Deep Space Optical Communications



Objectives:

- **Demonstrate deep space optical communication capability**
  - Designed for 0.1 to 2.7 AU
  - Sun-Earth Probe Angle > 25° (TBC)
- **Develop a Flight Laser Transceiver (FLT) for accommodation on Psyche spacecraft**
  - Downlink data-rate of **0.256 - 200 Mb/s**
  - Uplink data-rate of **[2 kb/s]**
  - Prime demonstration duration **2 years**
- **Develop ground network**
  - GLT for transmitting laser beacon out to 2.7 AU
  - GLR retrofitted with photon counting receiver
  - Mission Operations System

Project Manager (PM) : Bill Klipstein, (818)-354-2245
Project Technologist (PT): Abi Biswas

Sponsors:

STMD/TDM (flight), HEOMD/SCaN (ground), SMD (host)

Facilities:

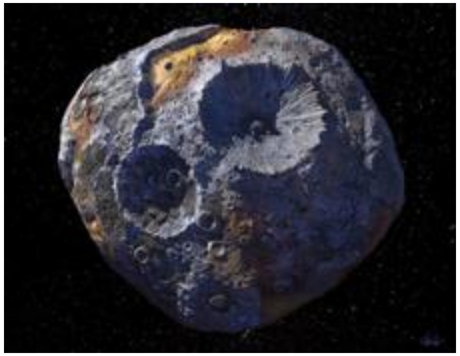
Optical Comm and Environmental Test Labs at JPL
Vendor site Labs and test facilities
Optical Communication Telescope Laboratory (OCTL)
Caltech Optical Observatories/Hale Telescope Observatory
Psyche mission host

Key Milestones:

FY14-16 GCD Technology Development Phase
FY17 Phase A Start, SRR/MDR
FY18 PDR
FY19 CDR
FY20 Downlink I+T start at JPL
FY21 start I+T at Hale and OCTL
FY22 ORR
FY23-25 Launch**,** Ops

DSOC on Psyche

- Explores a metal world: a nickel-iron protoplanet core, a Trojan asteroid at ~3.3 AU
- PI: Lindy Elkins-Tanton, ASU
- PM: Henry Stone, JPL
- S/C: Space-Systems Loral
- Excellent opportunity for a robust demonstration of optical comm out to ~3 AU in 1st 2 years
- Psyche's schedule:
  - Launch in Oct 2023 corresponds to delivery of DSOC to S/C in June, 2022

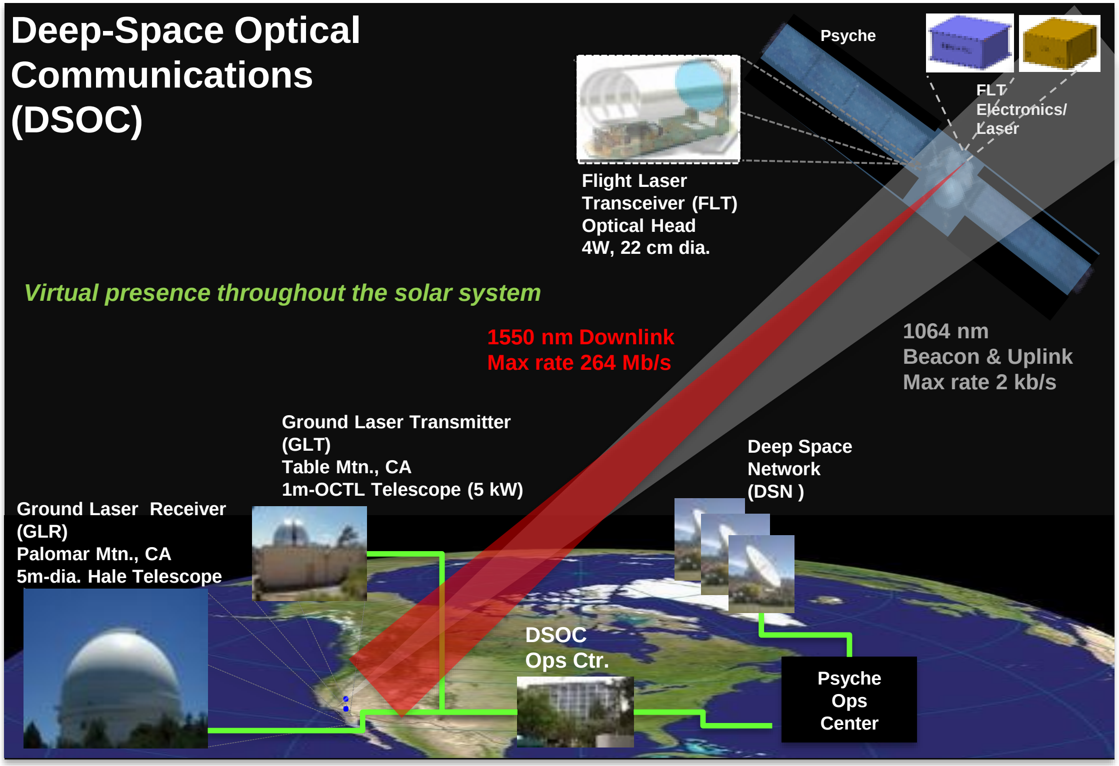


https://sese.asu.edu/research/psyche
https://www.facebook.com/Psyche-Mission-1598743977091187/

- DSOC to operate during cruise
- Earth flyby at 1 year followed by Mars flyby at 1.75 years is near ideal for a 2 year DSOC demo
  - System shake out and demonstration of high data rates at closer ranges
  - Reaches farthest design distance inside 2 year mission lifetime

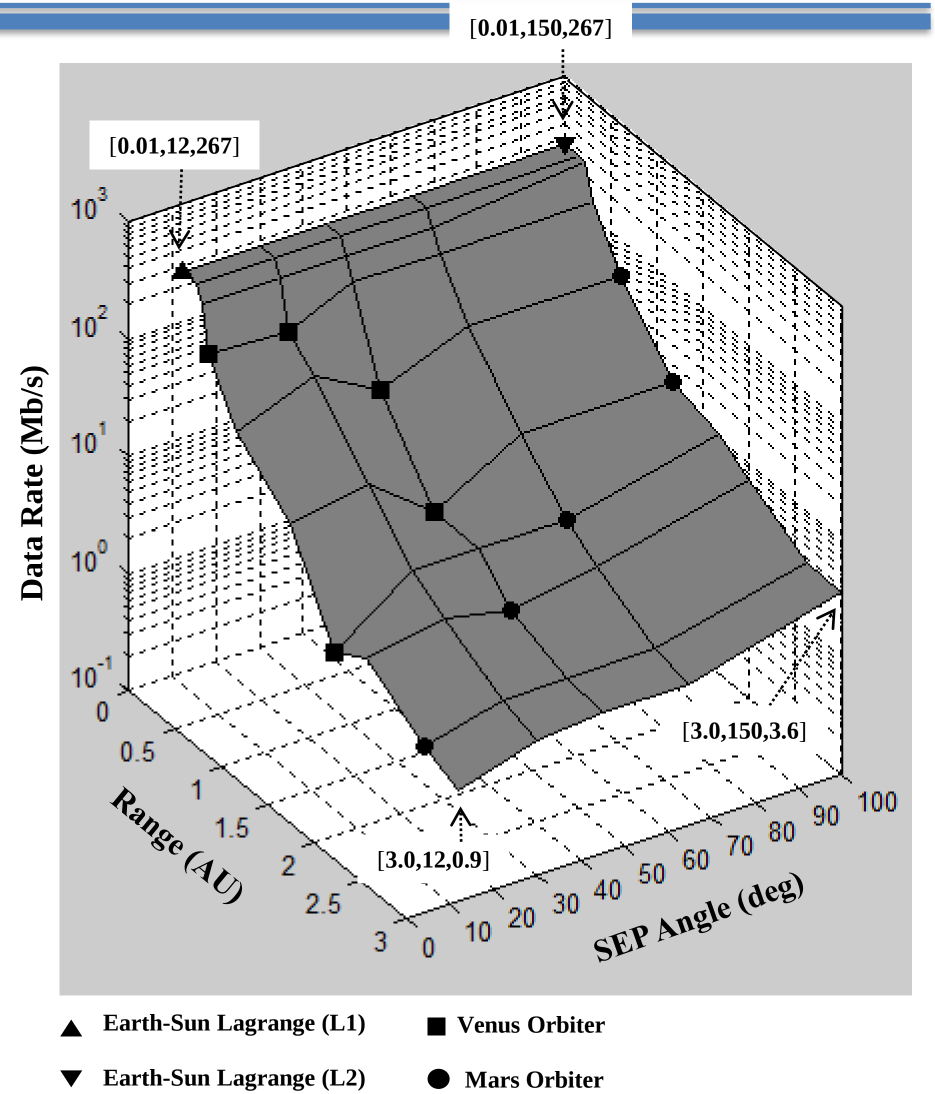
Overview

- **Beacon based architecture with existing ground assets for cost-effective demo**
  - Beacon laser beam serves as
    - A pointing reference
    - Low-rate uplink data carrier
    - Requires sensitive detector for dim beacon from deep-space range
  - Downlink is serially concatenated pulse position modulation (SCPPM)
    - Received with a photon-counting detector array retrofitted to 5 m diameter Hale telescope
- **Link demonstration constraints**
  - Ground Laser Receiver restricted to 25°(TBC) SEP angle
    - Expect link outages
- **Psyche Mission to host DSOC**
  - Psyche
  - Ranges from ~ 0.1 - 3 AU
  - Diverse sun angles, air-mass, time of day/year



Notional Link Performance

- **Range and additive background dependency photon-counting link throughput**
  - 1550 nm
  - 4 W laser average power
  - 22-cm aperture diameter
  - Serially concatenated pulse position modulation (SCPPM)
  - Nominal atmospheric conditions
  - 60° zenith angle
  - r0 (day) = 3.6 cm
  - r0 (night) = 5 cm
  - Min Sep 12°
  - 5 m dia. ground collector
  - Photon-counting receiver
  - At all other ranges 3-4.5 dB margin



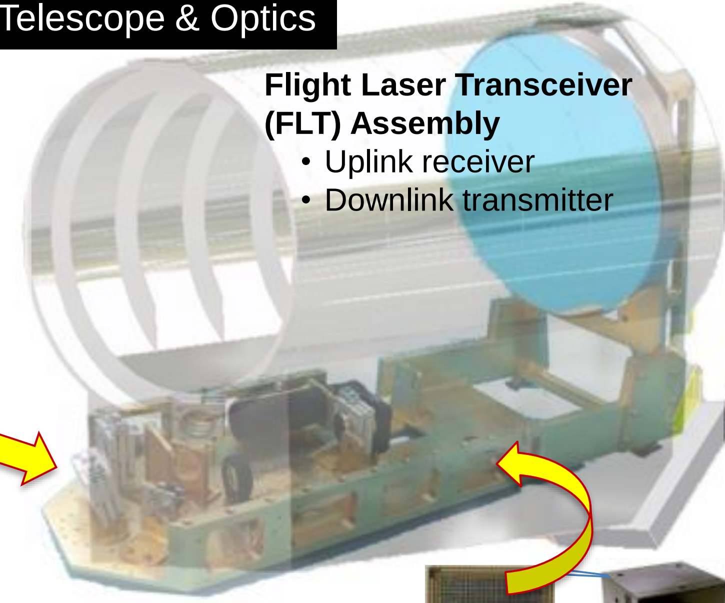
DSOC Space Flight Hardware

- **Deep-space optical communications Flight Laser Transceiver (FLT) characteristics**
  - ***Photon-efficient communications***
  - ***Off-axis Gregorian telescope***
  - ***Isolation Pointing Assembly***
  - ***Photon Counting camera***
  - ***High peak-to-average power laser transmitter***
  - ***Electronics***

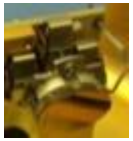
- **Assembly level technologies**
  - ***Developed by vendors and at JPL***

- **Integration & testing at JPL**

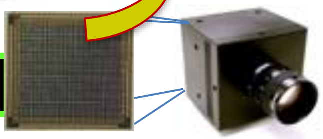
Telescope & Optics

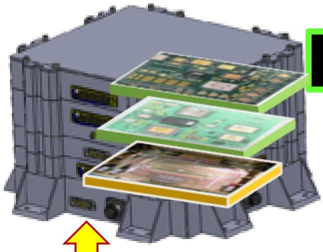


Point-Ahead Mirror

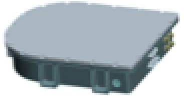


Photon-Counting Camera

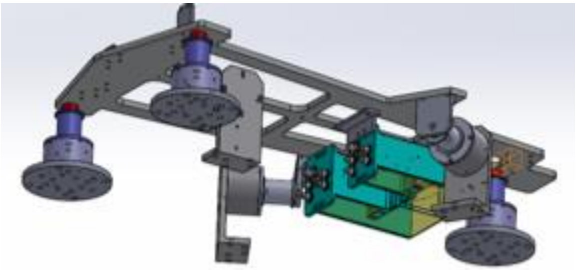




Electronics Box
– Electronics processing & control cards, firmware, software, clock



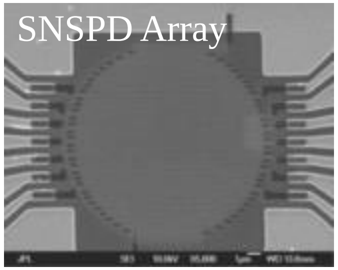
Laser Transmitter
– High Peak-to-average power

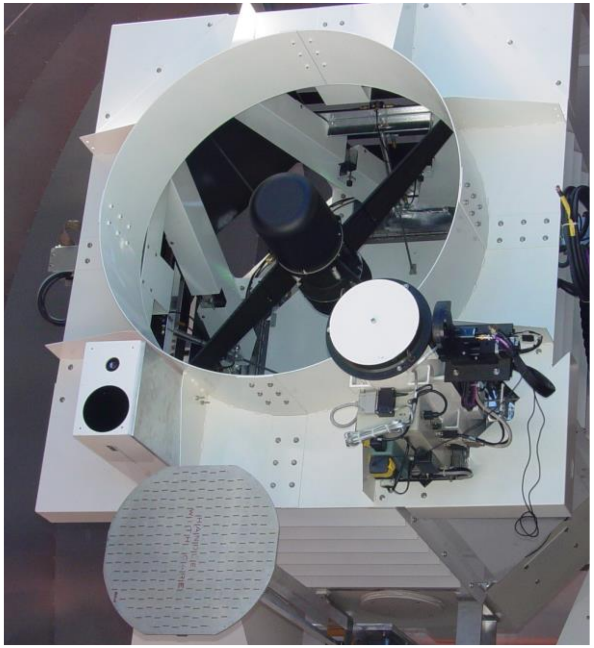


Isolation Pointing Assembly (IPA)
– Steering and line-of-sight (LOS) stabilization

DSOC Ground Characteristics

- Existing telescopes to be used for transmitter (OCTL) and Receiver (Hale telescope at Palomar Mountain)
- Laser transmitter for OCTL - baseline wavelength is 1064 nm
- Photon Counting receiver - Tungsten silicide (WSi) superconducting nanowire single photon detectors (SNSPD)
  - Developed at JPL
  - Large effective diameter array with read-out integration circuit





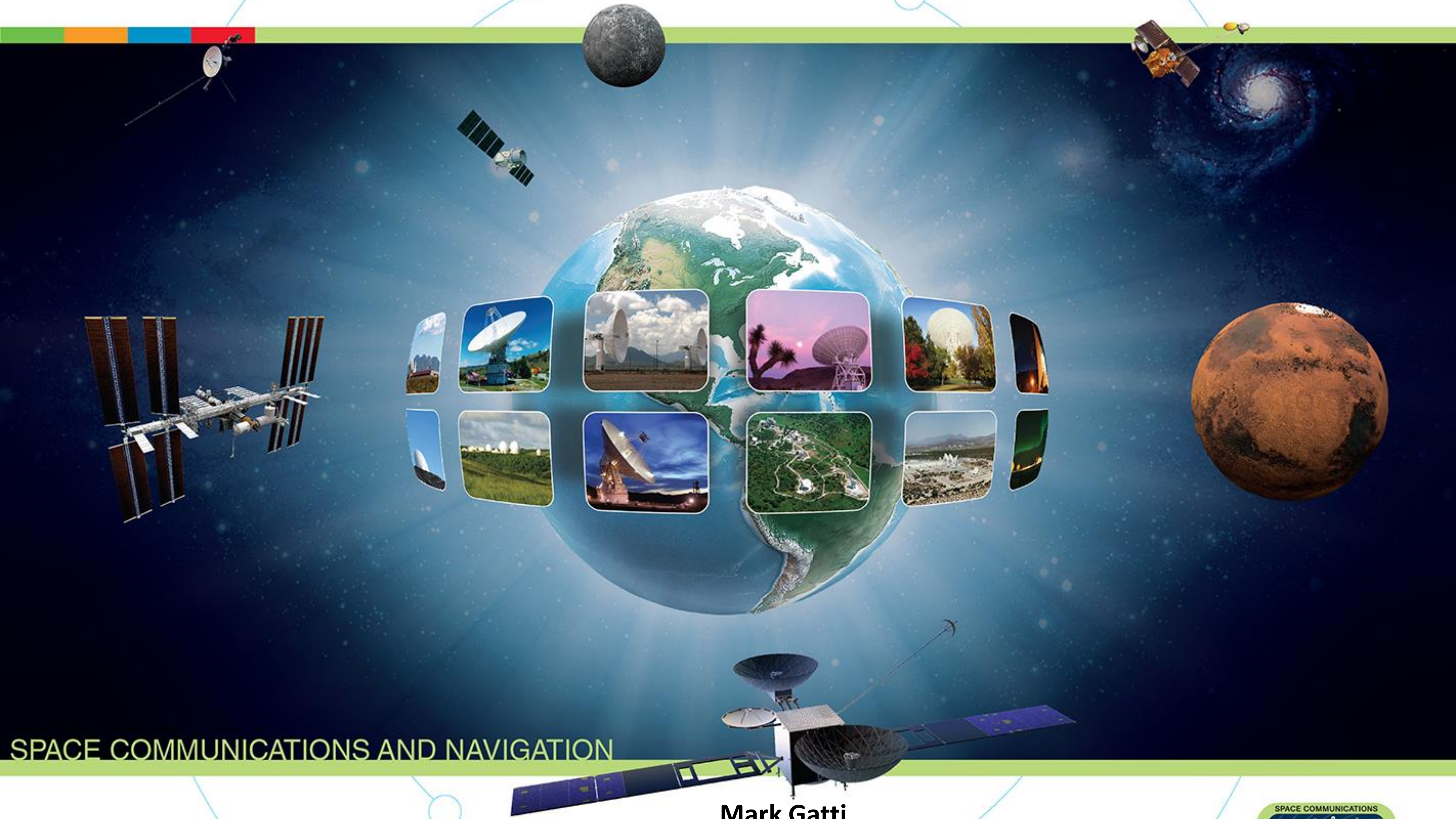
Optical Communication Telescope Laboratory (OCTL)
1 meter diameter

Palomar 5 meter Telescope

Summary

- **Technology Demonstration (TD) opportunity for laser communications**
  - Psyche mission to host TD
  - The DSOC Project is developing a flight and ground sub-system
  - Several new technologies will be tested and verified:
    - Space Photon Counting camera
    - Isolation Pointing Assembly
    - Flight Laser transmitter
    - Ground photon counting detector array
  - Gain deep space optical communications operational experience
    - Planning and scheduling link operations
    - Verifying link acquisition and tracking
    - Evaluating link performance under diverse conditions

Status: Potential 34 Meter Hybrid RF-Optical Antenna



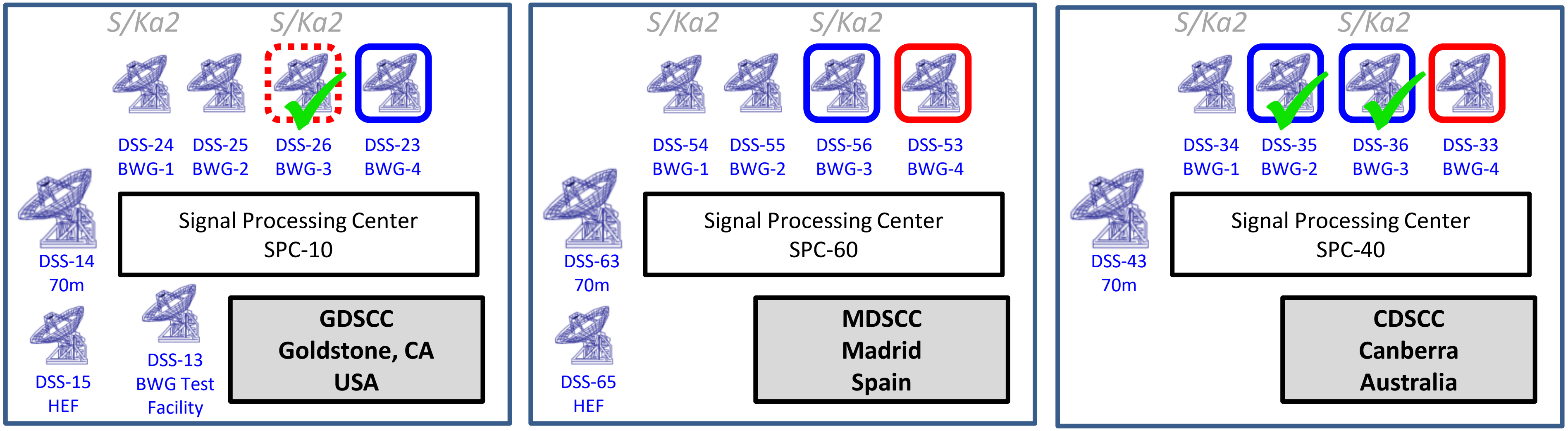
Mark Gatti
Manager, Ground Communications Section
Jet Propulsion Laboratory

Introduction

- JPL is proposing to incorporate an approximately 8 meter optical aperture into a 34 meter RF antenna
- Potentially part of the DSN Aperture Enhancement Project (DAEP)
  - No commitment from SCaN
  - All dates shown are notional but will be coordinated with DAEP
- Still in the initial systems engineering, technology development and validation stage

Thanks to Dan Hoppe and Brad Arnold for their contributions to this briefing

DAEP Rollout



DAEP Developments

80-kW TX Only

80-kW BWG

20-kW BWG

S S-Band Up/Dn

Ka2 26-GHz Dn

✓ Complete

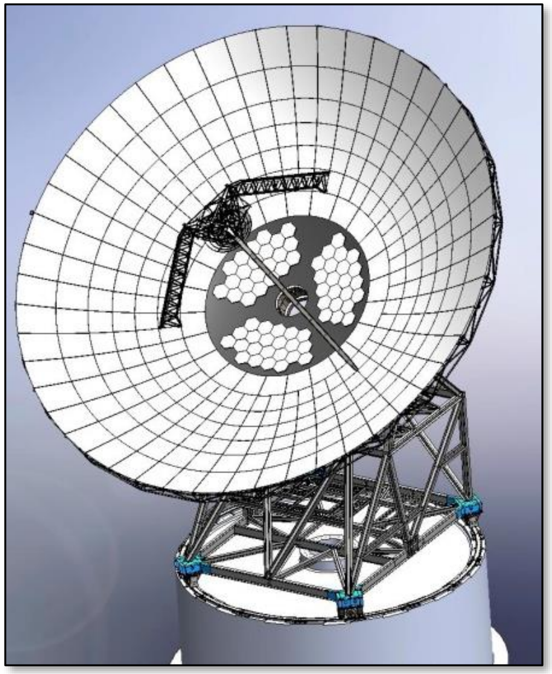
Station	XX/Ka	S	Ka2
DSS-26		10/2017	(TBD)
DSS-35	10/2014	-	-
DSS-36	10/2016	10/2016	(TBD)
DSS-56	03/2020	03/2020	03/2020
DSS-53	10/2020	-	-
DSS-23	10/2022	-	-
DSS-33	10/2024	-	-

Overview

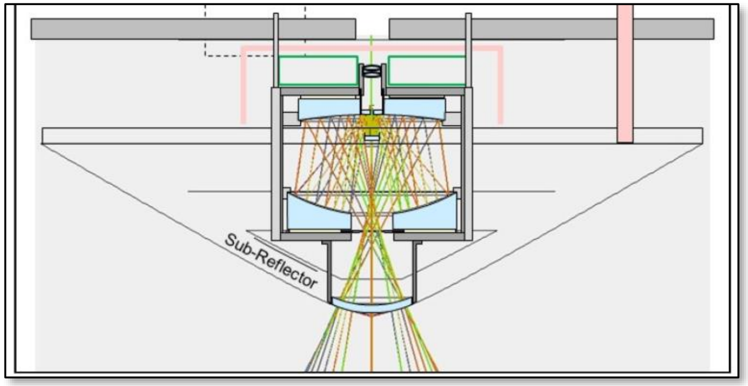
- Transformational development for SCaN for next generation deep space telecom, with feed forward for human exploration support
  - Operational Deep Space Optical capability
  - Ready to augment Discovery optical comm flight demo and early crewed missions
- Leverage earlier NASA-funded studies and tests, include key development gates minimize risk to NASA
- Implementation approach is to integrate new 8-m optical apertures with ongoing new 34m BWG antennas
- Minimize impact to baseline DAEP RF antenna schedule
  - Potentially, both hemispheres covered with optical deployments at GDSCC and CDSCC

Optical Design

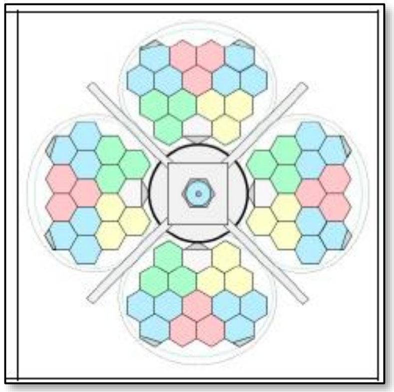
- Optical Design
  - Adapt two planned 34 m BWG for DAEP
  - Primary spherical mirrors replace inner RF panels
    - Small loss to RF performance – studies ongoing
  - Spherical aberration correction optics and receiver package located behind RF subreflector
  - Initial risk reduction development at GDSCC's DSS-13
    - Tripod vs. quadripod at production BWG



DSS-13 8 m Primary Surface Plan



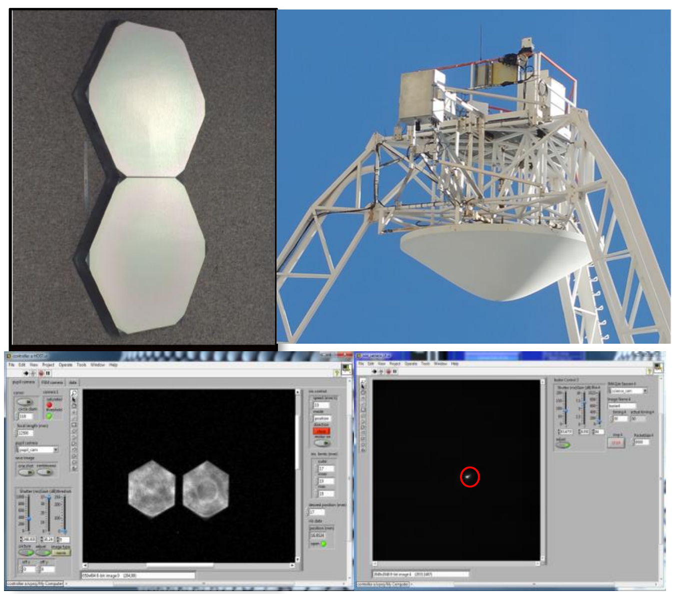
Spherical Aberration Correction Optics behind Subreflector



DAEP 34m Design

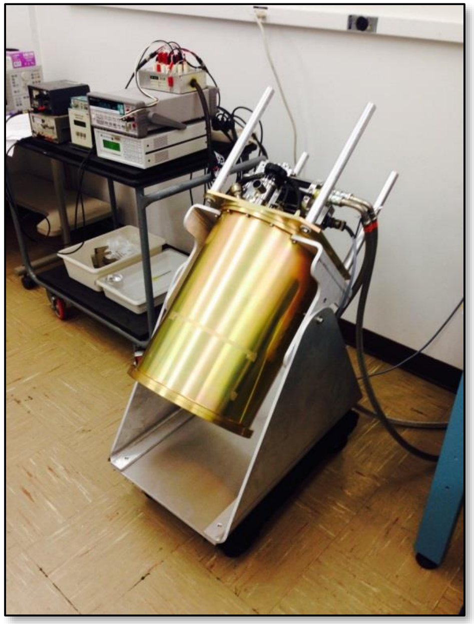
Developments To Date

- Early optical studies with pair of 35 cm panels DSS-13 complete, fielded second generation focal plane assembly last FY
- Low temperature cryo demonstrated (0.5 K at detector)
- Completed tipping and mechanical vibration tests, vetting design



DSS-13 2-Mirror Test

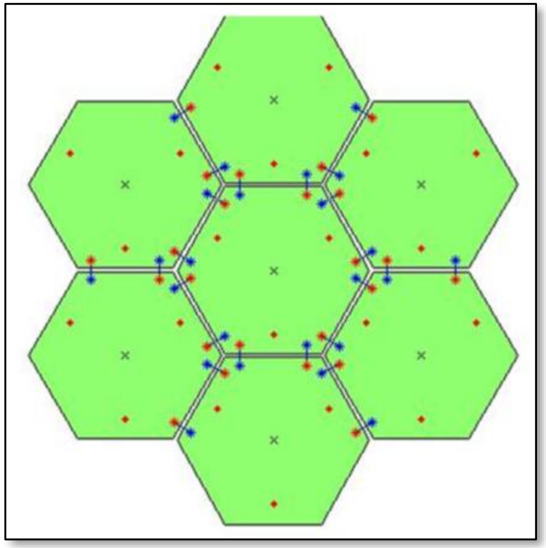
Cryo Package Prototype



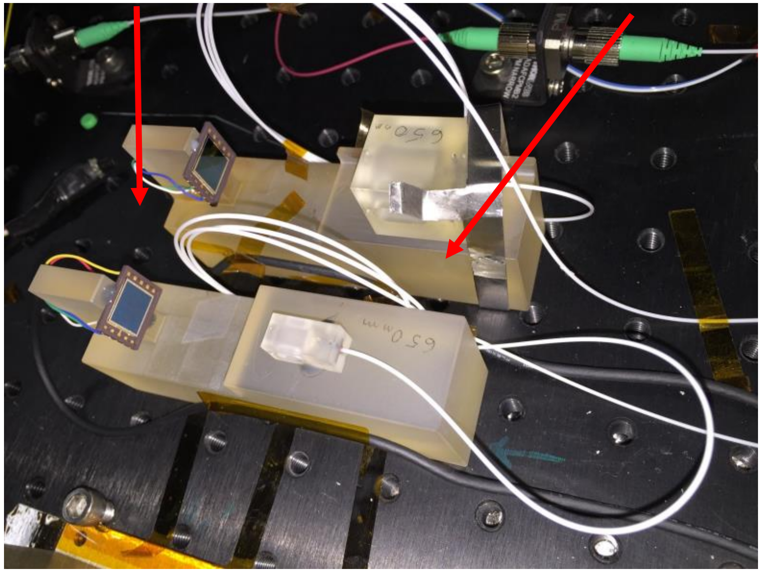
Cryo Tipping Test

Development to Date (cont'd)

- Edge sensors and control will be required to maintain overall surface alignments.
- Early development and testing of sensor system including outdoor testing is ongoing.



Edge Sensor Layout in Lattice



Early Testing of 2 Versions of the Detector System

Proposed Development Plan

- Preliminary development & analysis FY'17 – FY'19
  - Optical system analysis
    - Stray light analysis (complete by end of April)
    - Link budgets
    - Supportable solar angles
  - CDSCC atmospheric study
    - Equipment installation plus 2-3 years data collection
  - O&M considerations
  - Refine costing estimates

Proposed Development Plan (cont'd)

- Main technology demonstration and development gates
  - By Jan-2020
    - Seven 0.5m-element Non-Recurring Engineering study at DSS-13
    - Equivalent ~1.2 m demonstrated
    - Risk retired: Proof of concept demonstration showing alignment functionality of array with lower cost smaller optical elements
  - By Sep-2021
    - Sixteen 1.1 m production element "pod" + aberration correction optics at DSS-13
    - Equivalent ~4.15 m demonstrated
    - Risks retired: Performance of sub-array with full sized elements and optics demonstrated
  - Challenge: space based signals to test against (LCRD, stars, LEOs w/LRA, etc.)
    - Technical options will be considered
    - Psyche launches late 2022 or 2023 - augmentation to end of DSOC demonstration feasible

Proposed Development Plan (cont'd)

- Final build out and test
  - By Oct-2023
    - 64 elements (1.1 m) installed at DSS-13
    - Optical detector and receiver build, test and installation
    - Full equivalent 8 m demonstrated
  - By Oct-2024
    - Move equipment to DSS-23
    - Full integration and test complete
    - DSS-23 RF capability transferred to operations.
    - Optical capability will initially be run as a demonstration, until experience is gained in operating and maintaining the capability

Development Plan (cont'd)

- DSS-33
  - Start antenna build in FY'21
  - Complete full I&T and delivery to DSN by Oct-2026

- Additional requirements to modify BWG antenna
  - Preliminary analysis shows low risk forward, detailed analysis to go
  - Inner rings of RF panels not populated
  - RF subreflector reshaped, RF panels re-positioned
  - Antenna subreflector modified to accept Spherical Aberration Corrector, receiver and cryo equipment behind subreflector

10 m RF-Optical Hybrid

- 10-m equivalent diameter optical
  - Under study now
  - Early assessment suggests some redesign of 34m BWG would likely be required (f/D optics)

Conclusion

- The RF/Optical DSN antenna will be a transformational development
- Clear path to implementation with feed forward for next generation deep space telecom, including human exploration
- Plan minimizes impact to RF antenna development
- Delivers DSS-23/33 8 m optical hybrid antennas in 2024 and 2026
- Initial development and plan have been prepared
- Minimizes risk to NASA resources by scheduling two key development gates